WG1: KAON PHYSICS

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Overview

- Conveners: Johan Bijnens and Gino Isidori
- Flavianet average for e.g. V_{us}
- WG session talks
  - I. Rosell: Improving the theoretical status of $\pi(K) \to e\bar{\nu}_e[\gamma]$
  - B. Sciascia: KLOE perspectives on Kaon decays
  - J. Bijnens: Isospin violation at NNLO for $K_{\ell 3}$ and rare decays
  - D. Greynat: Progress on analytical expression of $K_{\ell 3}$ form factors at two loop order
  - R. Wanke: NA48/NA62 Status and Prospects of Semileptonic and Leptonic Kaon Decays

Overview

- Plenary talks (well planned at least): H. Neufeld, E. Passemar, A. Fuhrer, F. Mescia, B. Moussallam
- Many other talks relevant for Kaons
- Thanks to B. Sciascia for getting talks to work (and thanks to Microsoft for updating my laptop automatically into not working)

I. Rosell

Improving the theoretical status of $\pi(K) \to e\bar{\nu}_e[\gamma]$

Ignasi Rosell
Universidad CEU Cardenal Herrera
EuroFlavour'07

In collaboration with:
V. Cirigliano (Los Alamos)

JHEP **0710** (2007) 005 [0707.4464 [hep-ph]]
To appear in PRL [0707.3439 [hep-ph]]

I. Rosell

1. Motivation

i) $R^{(P)}_{e/\mu} \equiv \Gamma(P \to e\bar{\nu}_e[\gamma])/\Gamma(P \to \mu\bar{\nu}_\mu[\gamma])$ $(P = \pi, K)$ helicity suppressed

↓

sensitive probe af SM extensions

attention in SUSY

ii) Effects from weak-scale new physics $(\Delta R_{e/\mu})/R_{e/\mu} \sim 10^{-4} - 10^{-2}$

iii) Ongoing experimental searches
$$\begin{cases} (\Delta R^{(\pi)}_{e/\mu})/R^{(\pi)}_{e/\mu} \lesssim 5 \times 10^{-4} \\ (\Delta R^{(K)}_{e/\mu})/R^{(K)}_{e/\mu} \lesssim 3 \times 10^{-3} \end{cases}$$

iv) Strong dynamics cancels out partially in the ratio

↓

SM can reach this precision

Required $O(e^2p^4)$ corrections ←

present predictions:

$R^{(\pi)}_{e/\mu} = (1.2352 \pm 0.0005) \times 10^{-4}$ *

$R^{(\pi)}_{e/\mu} = (1.2354 \pm 0.0002) \times 10^{-4}$ **

$R^{(K)}_{e/\mu} = (2.472 \pm 0.001) \times 10^{-5}$ **

* Marciano and Sirlin ’93
** Finkemeier ’96

I. Rosell

Phenomenology (continuation)

$$R_{e/\mu}^{(\pi)} = (1.2352 \pm 0.0001) \times 10^{-4}$$
$$R_{e/\mu}^{(K)} = (2.477 \pm 0.001) \times 10^{-5} \ .$$

	$10^4 \cdot R_{e/\mu}^{(\pi)}$	$10^5 \cdot R_{e/\mu}^{(K)}$
This work	1.2352 ± 0.0001	2.477 ± 0.001
Marciano et al.	1.2352 ± 0.0005	
Finkemeier	1.2354 ± 0.0002	2.472 ± 0.001

Discrepancy at 0.2% level

NA48/3 plans to reach an uncertainty of 0.3%

I. Rosell

7. The individual $\pi(K) \to \ell\bar{\nu}_\ell$ modes

LO result

Universal short-distance EW correction

Kinoshita' 59

$$\Gamma_{P_{\ell 2[\gamma]}} = \Gamma^{(0)} \times \left\{1+\frac{2\,\alpha}{\pi}\log\frac{m_Z}{m_\rho}\right\} \times \left\{1+\frac{\alpha}{\pi}F(m_\ell^2/m_P^2)\right\} \times \left\{1-\frac{\alpha}{\pi}\left[\frac{3}{2}\log\frac{m_\rho}{m_P} + c_1^{(P)} + \frac{m_\ell^2}{m_\rho^2}\left(c_2^{(P)}\log\frac{m_\rho^2}{m_\ell^2}+c_3^{(P)}+c_4^{(P)}(m_\ell/m_P)\right) - \frac{m_P^2}{m_\rho^2}\,\tilde{c}_2^{(P)}\log\frac{m_\rho^2}{m_\ell^2}\right]\right\},$$

Studied at $O(e^2p^2)$:
Given in Knecht et al. '00
Estimated in Descotes-Genon et al. '05

This work $O(e^2p^4)$

The only remaining task: $c_1^{(P)}$ at $O(e^2p^4)$

Future work

J. Bijnens

ISOSPIN VIOLATION AT NNLO FOR $K_{\ell 3}$ AND RARE DECAYS

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Formfactor relations

$r(t) = 1 + \delta^2$ is always true, also for $r^-(t)$ and $r^0(t)$

Vector operator is I=1/2
$(m_u - m_d)(\bar{u}u - \bar{d}d)$ is I =1

$$
\begin{aligned}
f_\ell^{K^+\pi^0}(t) &= f_\ell^A(t) + \delta f_\ell^B(t) + \mathcal{O}(\delta^2)\,,\\
f_\ell^{K^0\pi^-}(t) &= f_\ell^A(t) - \delta f_\ell^D(t) + \mathcal{O}(\delta^2)\,,\\
f_\ell^{K^+\pi^+}(t) &= f_\ell^A(t) + \delta f_\ell^D(t) + \mathcal{O}(\delta^2)\,,\\
f_\ell^{K^0\pi^0}(t) &= f_\ell^A(t) - \delta f_\ell^B(t) + \mathcal{O}(\delta^2)\,,
\end{aligned}
$$

Photon exchange has $I = 0, 1, 2$, $I = 2$ part breaks relation

Relation also true for scalar currents $\bar{s}u$, $\bar{s}d$

$f_+(0)$

$$r_{0-}(0) = 1.02465 + 0.00587 - 0.00711 = 1.02341\,,$$

Palutan: KAON07

$$r_{0-exp} = 1 + \Delta_{SU(2)} = 1.0284 \pm 0.0040\,.$$

As we see, we obtain a reasonable agreement.

Callan-Treiman point

Callan-Treiman: $f_0\left(m_K^2 - m_\pi^2\right) = \frac{F_K}{F_\pi} + \mathcal{O}(m_u, m_d)\,.$

$\Delta_{CT} \equiv f_0\left(m_K^2 - m_\pi^2\right) - \frac{F_K}{F_\pi} = -3.5\,10^{-3}\,.$ (GL, iso)

$\Delta_{CT} = -6.2\,10^{-3}\,.$ NNLO using BT formulas

With δp^4 Calculated with $F_K/F_\pi = 1.22$

$$
\begin{aligned}
\Delta_{CT}^{K^+\pi^0} &= 15.1\,10^{-3}\,,\\
\Delta_{CT}^{K^0\pi^-} &= -5.6\,10^{-3}\,,\\
\Delta_{CT}^{K^+\pi^+} &= -9.4\,10^{-3}\,,\\
\Delta_{CT}^{K^0\pi^0} &= -26.4\,10^{-3}\,.
\end{aligned}
$$

D. Greynat

Progress on analytical expression of $K\ell_3$ form factors at two loop order

David Greynat[a]

In collaboration with

Roberto Bonciani[a], Christoph Haefeli[a], Roland Kaiser[b], Antonio Pich[a] and Eduardo de Rafael[b]

a Institut de Física Corpuscular – Valencia
b Centre de Physique Théorique – Marseilles

FlaviaNet Meeting – Orsay
14^{th} - 16^{th} November

J. Bijnens' web page http ://www.thep.lu.se/ bijnens/chpt.html

The chiral expansion of $f^{K\pi}$ is given by

$$f = \underbrace{f^{(2)}}_{\doteq 1} + f^{(4)} + f^{(6)} \tag{3}$$

From now, we are taking the two loops expression for $f^{K\pi}$ provided by J. Bijnens.
It involves scalar two loop D-dimensional integrals

$$V \doteq \int \frac{d^D k_1}{(2\pi)^D} \frac{d^D k_2}{(2\pi)^D} \frac{\text{Num.}}{\left[k_1^2 - m_1^2\right] \left[(k_1 - q)^2 - m_2^2\right] \left[(k_1 + k_2 - p)^2 - m_4^2\right]} \tag{4}$$

at the end 396 scalars integrals !

Necessity of a method to obtain a complete analytical expression.

Laporta's Algorithm

S.Laporta, Int. J. Mod. Phys. A 15 (2000) 5087

T. Gehrmann and E. Remiddi, Nucl. Phys. B 580 (2000) 485

R. Bonciani, P. Mastrolia and E. Remiddi, Nucl. Phys. B 661 (2003) 289

Every two loops amplitudes obey to the following form

$$\mathcal{I} = \int \frac{d^D k_1}{(2\pi)^D} \frac{d^D k_2}{(2\pi)^D} \frac{S_1^{n_1} \cdots S_N^{n_N}}{D_1^{\ell_1} \cdots D_L^{\ell_L}}$$

for S scalar products and D denominators.

1. Use the Integrate by parts relation (Stokes' theorem)

$$\int \frac{d^D k_1}{(2\pi)^D} \frac{d^D k_2}{(2\pi)^D} \frac{\partial}{\partial k_j^\mu} \left[v^\mu \frac{S_1^{n_1} \cdots S_N^{n_N}}{D_1^{\ell_1} \cdots D_L^{\ell_L}} \right] = 0$$

   for $v = k_1, k_2, p, q$.

2. Use Lorentz' invariance and discrete symmetries

Obtaining then the following representation

$$\int \omega_1$$

$$= \sum_{n=0}^{\infty}\sum_{k=0}^{\infty}\frac{(4\rho_1)^n}{n!}\frac{\rho_2^k}{k!}\Bigg(\Gamma\left[\begin{matrix}2-\epsilon-n\,,\,1-\frac{\epsilon}{2}-k\,,\,1-\frac{\epsilon}{2}-n\\ -n-k-\epsilon+2\,,\,3-\frac{3}{2}\epsilon-n-k\,,\,\frac{3}{2}-\frac{\epsilon}{2}-n\end{matrix}\right]$$

$$+\,\rho_2^{1-\frac{\epsilon}{2}}\Gamma\left[\begin{matrix}-k-1+\frac{\epsilon}{2}\,,\,2-\epsilon-n\,,\,1-\frac{\epsilon}{2}-n\\ \frac{3}{2}-\frac{\epsilon}{2}-n\,,\,2-\epsilon-n-k\,,\,1-\frac{\epsilon}{2}-n-k\end{matrix}\right]+4\rho_1\Gamma\left[\begin{matrix}1-\frac{\epsilon}{2}-k\,,\,1-\frac{\epsilon}{2}-n\,,\,-1+\frac{\epsilon}{2}-n\\ \frac{1}{2}-n\,,\,2-\epsilon-k-n\,,\,1-\frac{\epsilon}{2}-k-n\end{matrix}\right]\Bigg)$$

We doing the same processus for all 6 2-forms ω_j... To obtain finally the following behaviour after an ϵ-expansion

$$\bar{H}(m_\eta^2, m_K^2, m_K^2, m_\pi^2) \sim \frac{1}{\epsilon^2}\left[-\frac{1}{8}\left(2m_K^2+m_\eta^2\right)\right]+\cdots$$

in agreement with literature

Of course the epsilon-expansion and the cut of the infinite series are not obligatory and in this sense, we have an analytic expansion of the Master Integrals .

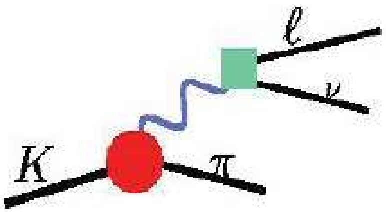
M. Caffo *et al.*, Nuovo Cimmento Vol. III, A, N 4 (1998)

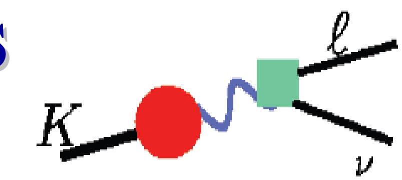
KLOE and NA48/NA62

- B. Sciascia gave a summary of (some of) the KLOE kaon results
- R. Wanke gave a summary of (some of) the NA48/NA62 kaon results
- No 20 minute summary can give tribute to all the Kaon results from these experiments
- So summary of summaries ????????

B. Sciascia

KLOE perspectives on kaon decays



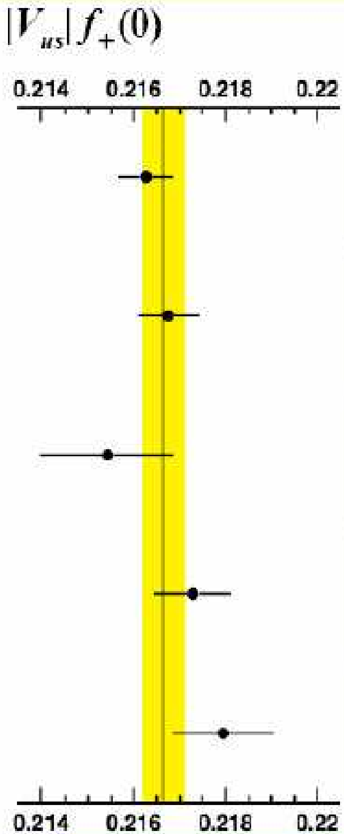


- **Vus: K_S decays**
  K_L decays and lifetime
  $K^{\pm}$ decays and lifetime
  K_L and $K^{\pm}$ semileptonic form factors

- **Ke2/Kμ2.**

B. Sciascia, LNF INFN
for the KLOE collaboration
FlaviaNet meeting - Orsay, 14 November 2007

V_{us} *from* $K_{\ell 3}$ *data – FlaviaNet@EPS'07*



FlaviA net Kaon WG

		% err	BR	τ	Δ	Int
			Approx. contrib. to % err from:			
$K_L e3$	0.21625(60)	0.28	0.09	0.19	0.15	0.09
$K_L \mu 3$	0.21675(66)	0.31	0.10	0.18	0.15	0.15
$K_S e3$	0.21542(144)	0.67	0.65	0.03	0.15	0.09
$K^\pm e3$	0.21728(84)	0.39	0.26	0.09	0.26	0.09
$K^\pm \mu 3$	0.21794(111)	0.51	0.40	0.09	0.26	0.15

Average: $|V_{us}|\,f_+(0)$ = 0.21664(48) χ^2/ndf = 2.88/4 (58%)

3 kaon@KLOE – B. Sciascia – FlaviaNet, Orsay, 14 Nov 2007

B. Sciascia

$K^{\pm}$ *BR and lifetime measurements*

Absolute BR($K^{\pm}_{e3}$) and BR($K^{\pm}_{\mu 3}$), tagging with $K^{\pm} \to \mu^{\pm}\nu$ and $K^{\pm} \to \pi^{\pm}\pi^{0}$: 8 measurements in total, each with 10^5

KLOE final **ArXiv: 0707.2532**	**BR($K^{\pm}_{e3}$) = 4.965(52)%** **BR($K^{\pm}_{\mu 3}$) = 3.233(39)%**	at $\tau_{\pm}^{(0)}$ = 12 .385 ns, with $dBR/BR = -0.5 d\tau_{\pm} / \tau_{\pm}$

$K^{\pm}$ lifetime using two different methods:

$\tau_{\pm}$ from the K decay length, using tagged vertices in DC

$\tau_{\pm}$= 12.367(44)(65) ns

$\tau_{\pm}$ from the K decay time, using γ from $K^{\pm} \to \pi^{\pm}\pi^{0}$ decays

$\tau_{\pm}$= 12.391(49)(25) ns

KLOE preliminary **ArXiv: 0705.4408**	**$\tau_{\pm}$= 12.384(48) ns**	Combined result, ρ = 0.34 **Final result: $\Delta\tau/\tau$ = 0.25%**

Absolute BR($K^{\pm} \to \pi^{+}\pi^{0}$). Use $K^{-} \to \mu^{-}\nu$ to tag 2-body decays. Count $K^{+} \to \pi^{+}\pi^{0}$ from decay-momentum spectrum.

KLOE preliminary **ArXiv: 0707.4631**	**BR($K^{+}_{\pi 2}$) = 0.20658(65)(90)**

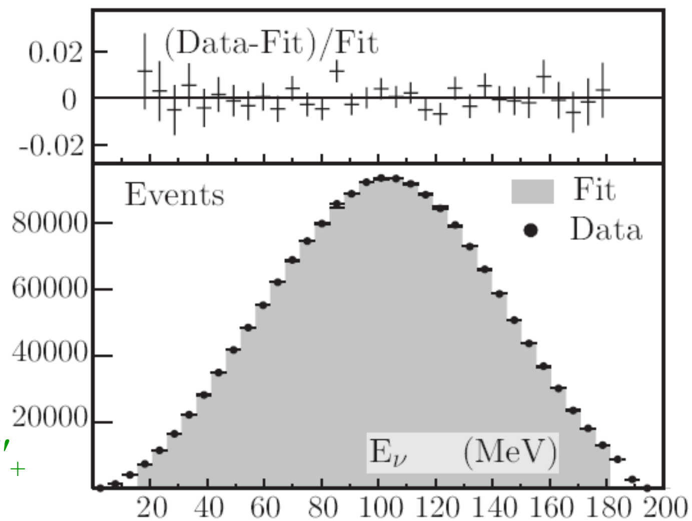
B. Sciascia

$K_{L\mu3}$ form factor slope λ_0

- Standard method: fit t-spectrum, $t=(p_K-p_\pi)^2$
- Difficult π/μ separation at low energy → problems in keeping low systematics on λ_0 (at the end of spectrum: +1% in signal counts implies +15% in λ_0).
- Fit E_ν spectrum: lose sensitivity ×2-3 on $\sigma_{stat}(\lambda_0)$; becomes ×1.3 if combined fit with K_Le3.

Obtain λ'_+, λ''_+, and λ_0 fitting $K_L\mu3$ data (correlation between λ_0' and λ_0'' = - 99.96%)

$$\lambda'_+ = (22.3 \pm 9.8_{\rm stat} \pm 3.7_{\rm syst}) \times 10^{-3}$$
$$\lambda''_+ = (4.8 \pm 4.9_{\rm stat} \pm 1.6_{\rm syst}) \times 10^{-3}$$
$$\lambda_0 = (9.1 \pm 5.9_{\rm stat} \pm 2.6_{\rm syst}) \times 10^{-3}$$



Combined fit with K_Le3 results for λ'_+ and λ''_+

$$\lambda'_+ = (25.6 \pm 1.5_{\rm stat} \pm 0.9_{\rm syst}) \times 10^{-3}$$
$$\lambda''_+ = (1.5 \pm 0.7_{\rm stat} \pm 0.4_{\rm syst}) \times 10^{-3}$$
$$\lambda_0 = (15.4 \pm 1.8_{\rm stat} \pm 1.3_{\rm syst}) \times 10^{-3}$$

FFe3 PLB 632 (2006)
FFμ3 final ArXiv: 0710.4470

13 **kaon@KLOE – B. Sciascia – FlaviaNet, Orsay, 14 Nov 2007**

B. Sciascia

FFe3 and FFμ3 using $K^{\pm}$

• No ambiguity on lepton charge assignement (for both Ke3 and Kμ3)
• No π–μ ambiguity because of π^0 presence

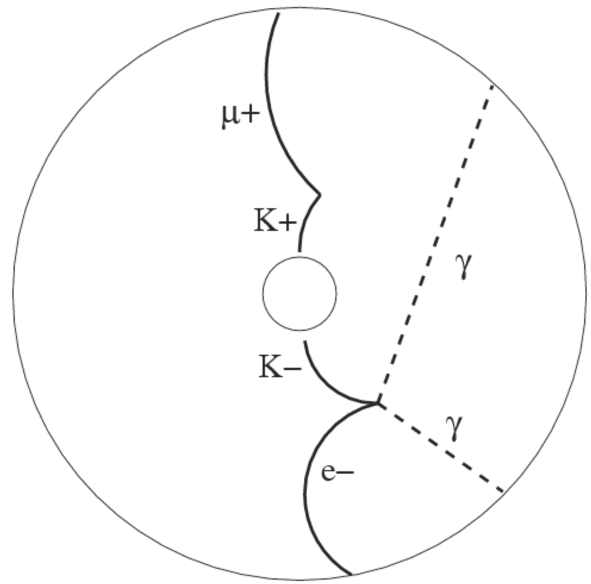
→ **Fit of t spectrum, $t = (p(K)-p(\pi^0))^2$**

• **Using BR selection expect 2.9 M of Ke3 and 1.9 M of Kμ3 in 2001/5 data.**
- Modifying the tag wrt the BR(Kℓ3) measurements, we expect:

Ke3: up to 5.9 M

Kμ3: up to 2.5 M

Respect to BR analysis, need to improve purity at a cost of some efficiency.



Analysis just started, very good perspectives

B. Sciascia

Conclusions

$|V_{us} f_+(0)|$ determination using Kℓ3 decays:

World average at the 0.2% level using five Kℓ3 modes.

Good compatibility between different modes (χ^2/dof = 2.9/4).

KLOE goals for the next year:

- K_L lifetime, aiming to reach 0.2-0.3% accuracy
- BR(K_Se3) , aiming to reach 0.6% accuracy
- BR($K^\pm \to \pi^\pm \pi^+ \pi^-$)
- Form factors of semileptonic $K^\pm$.

R_K:

KLOE can reach ~1% accuracy.

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R. Wanke

NA48/NA62 Status and Prospects of Semileptonic and Leptonic Kaon Decays

Rainer Wanke

Institut für Physik, Universität Mainz

EuroFlavour'07

Orsay, November 14, 2007

R. Wanke

Overview

NA48/NA62 K_{l3} and K_{l2}:

- **1999 K_L running (NA48):**

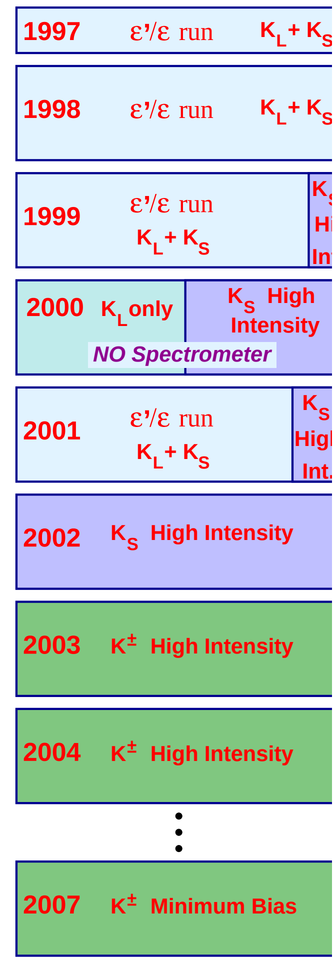
  $K_{L\,e3}$ branching ratio and form factors,
  $K_{L\,\mu3}$ form factors, $K_{L\,e3\gamma}$

- **2003 and 2004 $K^\pm$ running (NA48/2):**

  $K^\pm_{e3}$, $K^\pm_{\mu3}$ branching ratios, $K^\pm_{l3}$ form factors,
  $\Gamma(K_{e2})/\Gamma(K_{\mu2})$

- **2007 K^+ running (NA62):**

  High statistics $\Gamma(K_{e2})/\Gamma(K_{\mu2})$.
  Possibility for $K^\pm_{l3}$, $K_{L\,l3}$



All NA48 Semileptonic and Leptonic Analyses:

Minimum-bias data for precision measurements
$\Longrightarrow$ High trigger efficiencies, small systematics.

Rainer Wanke EuroFlavour'07, Orsay, November 14, 2007 – p.2/18

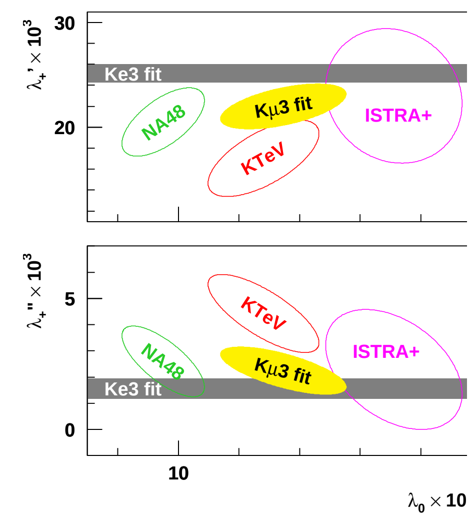
R. Wanke

K_L *Semileptonics — Form Factors*

$\mathbf{K_L}$ form factor slopes from NA48 1999 data:

Channel	$\lambda'_+ \times 10^3$	$\lambda''_+ \times 10^3$	$\lambda_0 \times 10^3$
$\mathbf{K_L e3}$ (PLB 604 (2004) 1)	28.0 ± 2.4	0.4 ± 0.9	
$\mathbf{K_L \mu 3}$ (PLB 647 (2007) 341)	16.8 ± 3.3	4.0 ± 1.4	9.1 ± 1.4

- $\mathbf{K_L e3}$ data agree well with other experiments within errors (although no quadratic slope seen).
- $\mathbf{K_L \mu 3}$ result on λ_0 does not agree at all with other experiments. (In particular, when correlations are taken into account.)
- Indication for right-handed currents in $\mathbf{K_L \mu 3}$, but again not confirmed by other experiments.



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R. Wanke

$K^{\pm}$ *Semileptonics — Branching Fractions*

Eight hours of 2003 data-taking with minimum bias trigger:

- About **89000 reconstructed** $\mathbf{K^{\pm}_{e3}}$ and **77000** $\mathbf{K^{\pm}_{\mu 3}}$ decays.

  $\Longrightarrow$ Quite enough for high-precision BR measurement.

$$\begin{aligned} \mathbf{R_{Ke3/K2\pi}} &= \mathbf{0.2470 \pm 0.0009 \pm 0.0004} \\ \mathbf{R_{K\mu3/K2\pi}} &= \mathbf{0.1637 \pm 0.0006 \pm 0.0003} \\ \mathbf{R_{Ke3/K\mu3}} &= \mathbf{0.1663 \pm 0.0003 \pm 0.0001} \end{aligned}$$

- Result dominated by statistical error.

Determination of $\mathbf{V_{us}}$: (using Br$(K_{2\pi} = 0.2092 \pm 0.0012)$)

$$\mathbf{|V_{us}| \times f_{+}(0) \;=\; 0.2188 \pm 0.0012}$$

R. Wanke

$K_{e2}/K_{\mu 2}$

Two preliminary NA48 measurements from **2003/2004 data:**

- **NA48/2 (2003 data), presented in 2005:**
  - About 4000 signal events from normal running period.
  - Systematics dominated by trigger efficiencies.

$$\mathbf{\Gamma(K_{e2})/\Gamma(K_{\mu 2}) = (2.416 \pm 0.043 \pm 0.024) \times 10^{-5}}$$

- **NA48/2 (2004 data), presented in 2007:**
  - About 4000 signal events from special minimum bias trigger.
  - Small systematics, except background.
    (measured from data $\longrightarrow$ large statistical uncertainty in syst. error.)
  - Completely uncorrelated with 2003 measurement.

$$\mathbf{\Gamma(K_{e2})/\Gamma(K_{\mu 2}) = (2.455 \pm 0.045 \pm 0.041) \times 10^{-5}}$$

Both results in agreement with each other, PDG, KLOE and SM theory.

R. Wanke

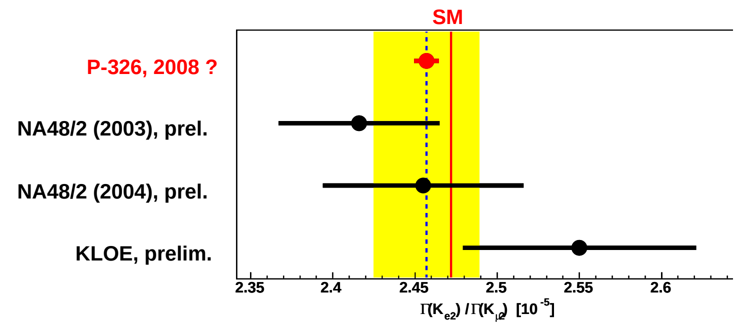
$K_{e2}/K_{\mu2}$ — *Expectations from 2007*

Expected precision on $K_{e2}/K_{\mu2}$:

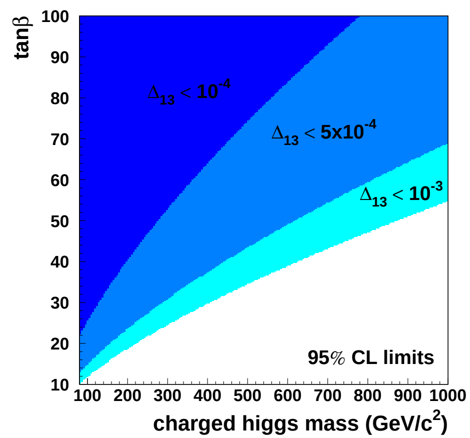
- Statistical: $\approx \pm \mathbf{0.3}\%$
- Systematic: $\leq \pm \mathbf{0.2}\%$

In total expected:

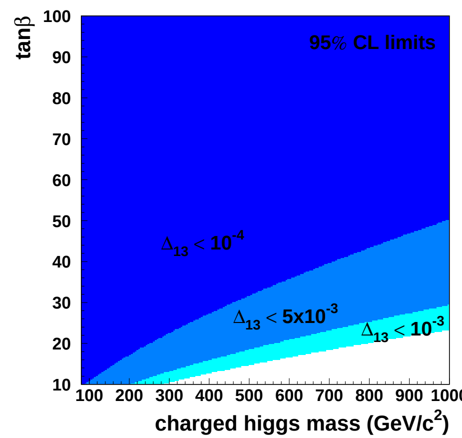
$$\sigma(\mathbf{R_K})/\mathbf{R_K} \approx \pm \mathbf{0.35}\%$$



2007:



Next year?!
same R_K central value



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R. Wanke

First Measurement of $K^\pm \to \pi^\pm e^+ e^- \gamma$

In whole 2003/2004 $\mathbf{K^\pm}$ data: (CERN-PH-EP/2007-033)

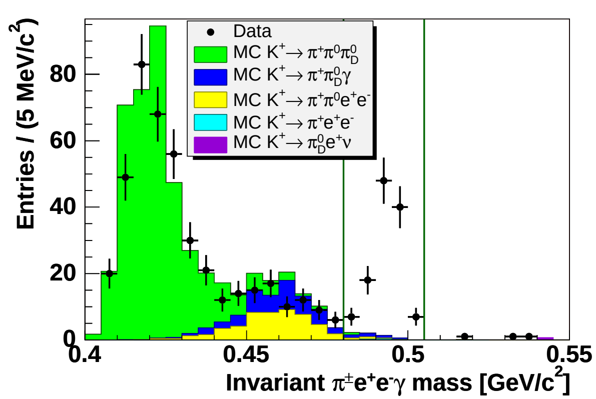
- **120 $\mathbf{K^\pm \to \pi^\pm e^+ e^- \gamma}$ signal candidates** (Bkg: $\mathbf{7.3 \pm 1.7}$ events)

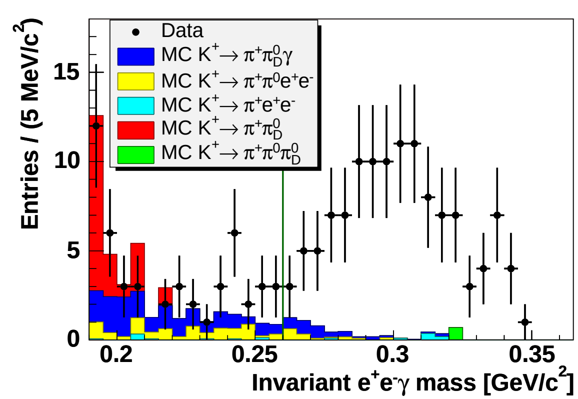
  $\Longrightarrow$ $4\times$ the published $K^\pm \to \pi^\pm \gamma\gamma$ statistics!

- Model-independent branching fraction:

  $$\mathbf{Br}(\mathbf{K^\pm \to \pi^\pm e^+ e^- \gamma, m_{ee\gamma} > 260\,MeV})$$
  $$= (\mathbf{1.19 \pm 0.12_{stat} \pm 0.04_{sys}}) \times \mathbf{10^{-8}}$$

- $\hat{\mathbf{c}}$ **extraction:** $\hat{\mathbf{c}} = \mathbf{0.90 \pm 0.45}$





Rainer Wanke EuroFlavour'07, Orsay, November 14, 2007 – p.17/18

Conclusions

Expect more Kaon results in theory and experiment in

EUROFLAVOUR08